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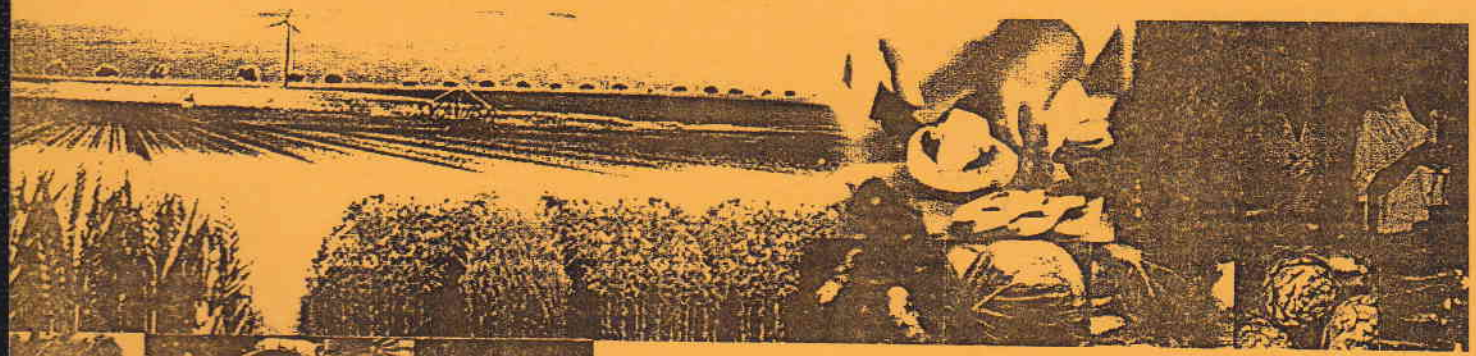

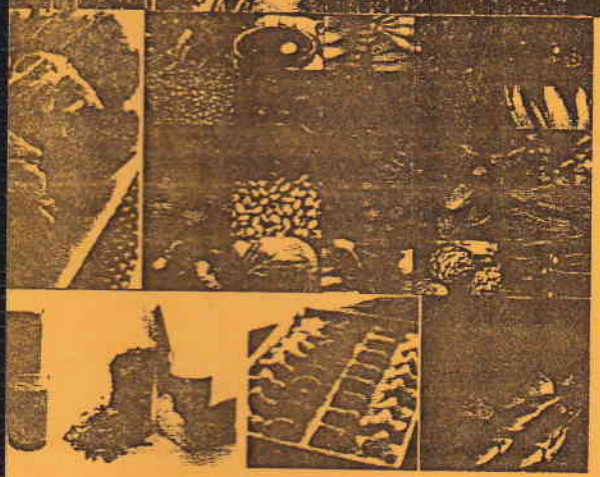

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PAPER OF ORAL PRESENTATION (Cont'd)

VOLUMETRIC-SHRINKAGE MODEL OF COCOA BEANS

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ABSTRACT

This study was intended to observe the volumetric shrinkage of cocoa beans from several different clones during the thin layer drying process. Five cocoa clones, were used, namely Sulawesi-1, SCA-6, DRC-16, ICCRI-04 and Sulawesi-2. The thin-layer drying process was performed using a tray dryer, Model EH-TD-300 Eunha Fluid Science. Drying air velocity and temperature were set to 1.3 m/s and 47^{0}C, respectively. Observations on dimensional reduction (length, width and thickness) were conducted on the elapsed drying time of 0, 1, 2, 4, 8, 17, 35, and 39 hours which provided eight different levels of sample moisture contents. Observed dimensional reductions were then transformed into volume shrinkage. The ratio of volume shrinkage (volume at elapsed drying time divided by the initial volume) for each cocoa clone was plotted against the bean moisture contents. Bala and Woods, Correa et al., linear, and polynomial-quadratic models were then fitted to this volume shrinkage behavior. Research results strongly indicate that among these models, the polynomial-quadratic model is the best model to represent the volume shrinkage of cocoa beans for all clones observed. R^2 reaches up to 0.99.

Key words: *volumetric shrinkage, cocoa bean, thin-layer drying*

INTRODUCTION

Cocoa (Theobroma cacao L.) is one of the primary estate crops in Indonesia. Indonesia has even been listed as the third largest cocoa producen country after Cost de'Ivory and Ghana during the last several years. At the provincial level, South Sulawesi is one of the cocoa centers in Indonesia. The export value of cocoa beans from this province is tremendously high compared to other crops (Panlibuton, 2004; AIKI in, 2006; and Muhidong, 2007). Nonetheless, Indonesian cocoa is considered to be a low quality cocoa and mostly unfermented. Mouldy bean is also another factor that affects the quality level (Muhidong, 2008).

As a prime estate crop, the existing of various cocoa clones may also increase the cocoa quality variability. Unfortunatley, research on cocoa quality related factors is relatively less progressive compared to the development of new clones. As a result, the engineering properties of the cocoa bean of the new clones are not well established, including the volume shrinkage of the beans during the drying process. This study was intended to observe the volumetric shrinkage of cocoa beans from several different clones during the thin layer drying process. Research on cocoa bean dimension characteristics was indeed studied by Oyedokun et al. (2011). Nonetheless, the length, width, and thickness characteristics were not linked with other parameters, such as moisture content and drying time.

The crop shrinkage, excluding recent cocoa clones, were intensively studied by some researchers. Among others, Correa et

al. (2004) observed coffee berry shrinkage. Abbasi et al. (2009) scrutinized the behavior of onion slice shrinkage during the thin layer drying process. A similar approach was also applied by Seifi and Alimardani (2010) when examined the relationship of the corn porosity and moisture contents.

MATERIALS AND METHOD

The research was conducted during the month of June 2011 at the Processing Laboratory of Agricultural Engineering Department - Faculty of Agriculture - Hasanuddin University, Indonesia. Cocoa samples were taken from local cocoa famers in Enrekang Regency - South Sulawesi. Five cocoa clones were used, namely Sulawesi-1, SCA-6, DRC-16, ICCRI-04 and Sulawesi-2. The thin-layer drying process was performed using a tray dryer, Model EH-TD-300 Eunha Fluid Science. Drying air velocity and temperature were set to 1.3 m/s and 47^0C, respectively. Observations on dimensional reduction (length, width and thickness) using a vernier-caliper were conducted on the elapsed drying time of 0, 1, 2, 4, 8, 17, 35, and 39 hours which provided eight different levels of sample moisture contents. Observed dimensional reductions were then transformed into a volume shrinkage. The ratio of volume shrinkage (volume at elapsed drying time divided by the initial volume) for each cocoa clone was plotted against the bean moisture contents. Bala and Woods, Correa et al., linear, and polynomial-quadratic models were then fitted to this volume shrinkage behavior.

Cocoa bean volume was calculated following the method used by Corrêa et al. (2004) as follows:

$$V = (1/6)\,(\pi.a.b.c)$$

where:
V, a, b, and c are volume, length, width, and thickness of the cocoa bean, respectively.

The volume shrinkage (V_f) was then calculated under the following formula:
$V_f = V_m / V_o$, where
V_m = Cocoa bean volume corresponding to the moisture content after the elapsed drying time m, and
V_o = Cocoa bean volume corresponding to the initial moisture content.

The relationship of the V_f value and the moisture content (dry basis, d.b.) were then evaluated using the following models:

Table 1. List of equations being evaluated to present the cocoa bean shrinkage behavior.

Equation Tag	Mathematical Model
Rahman Equation (1995)*)	$V_f = 1 - b.(U-U_o)$
Adapted Bala & Wood's Equation (1984)*)	$V_f = 1 - a.\,(1 - \exp((b).(U-Uo)))$
Corrêa et al. Equation (2004)*)	$V_f = 1 / (a + b.\exp(U))$
Proposed Model	$V_f = a.U + b.U^2 + c$

*) Source: Corrêa et al. (2004)

Uo and U are the cocoa bean initial moisture content (d.b.) and the moisture content (d.b.) at a certain elapsed drying time, respectively.

The equations were then evaluated using the SPSS Software. The model with the highest R^2 value will be considered as the best model to represent the shrinkage behavior of the cocoa bean being observed.

RESULTS AND DISCUSSIONS

The bean length, width, and thickness reductions when the moisture contents of the cocoa beans decreased across the drying time were displayed in Figures 1, 2, and 3. These figures strongly indicated that a significant decrease on a bean length, width, and thickness occurred as the moisture content declined during the drying process for all clones observed. It was also found that the downward trend was different from one clone to another. The DRC 16 clone seemed to have a higher dimension reduction rate compared to the other clones. Unfortunately, this research was not designed to deeply explore this phenomenon.

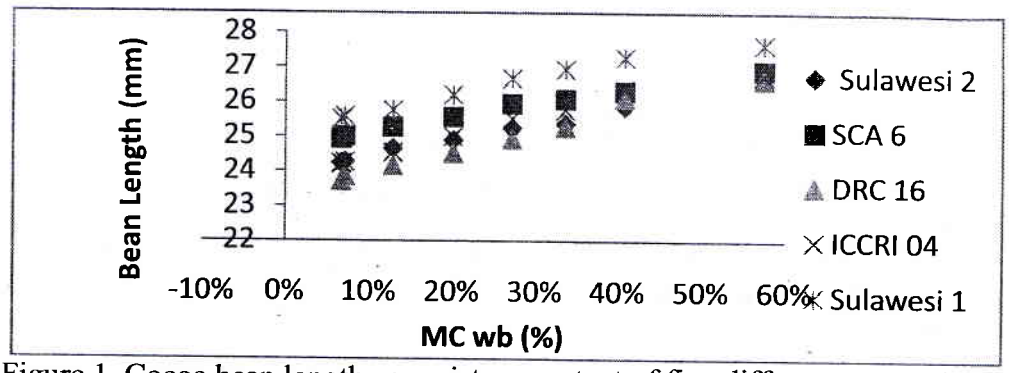

Figure 1. Cocoa bean length vs moisture content of five different cocoa clones

Sample volume shrinkage was depicted in Figure 4. This figure even emphasized that the volume shrinkage of the DRC clone was the bigest one, consistent with its dimensional (length, width, and thickness) behavior. While the clone with the smallest volume shrinkage was found on Sulawesi-1 clone.

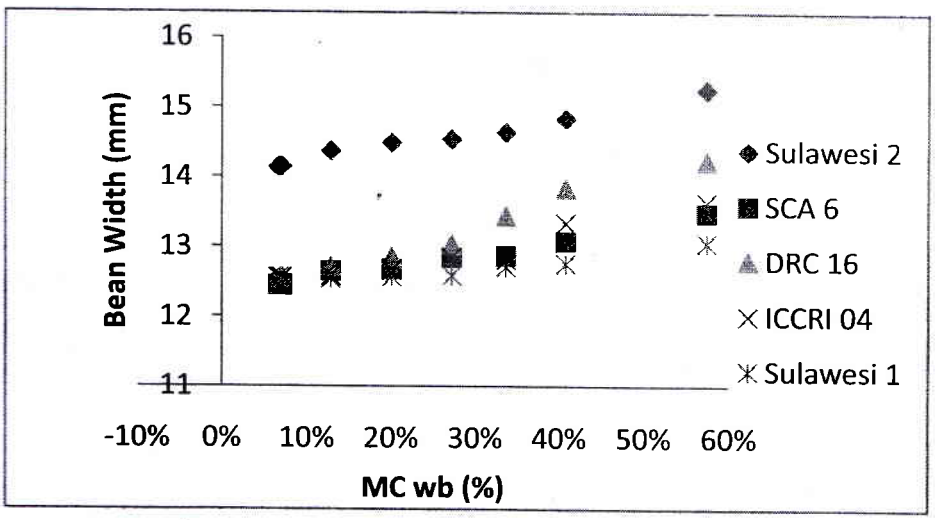

Figure 2. Cocoa bean width vs moisture content of five different cocoa clones

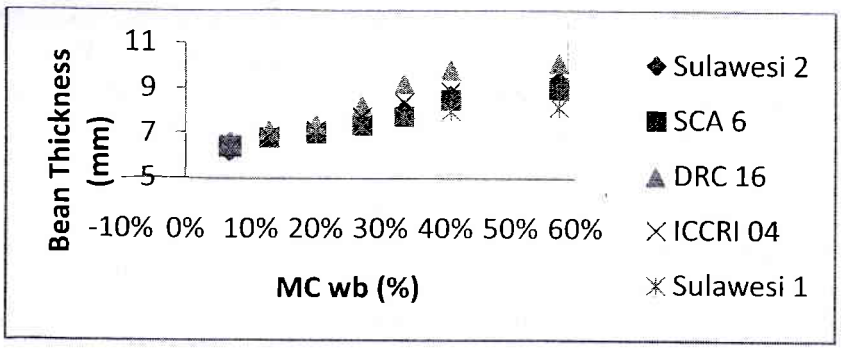

Figure 3. Cocoa bean thickness vs moisture content of five different cocoa clones

The behavior of the volumetric shrinkages as shown on Figure 4 provided an initial guess that their trends might follow linear, exponential, or polynomial manners. This was exactly in line with the four alternative models provided above. Curve fitting using the SPSS Software under the non-linear regression facility was used to estimate all parameters (a, b, and c) involved in the equations. Their R^2 values were also calculated under this facility. The result summary of this caclculation was shown in Table 2.

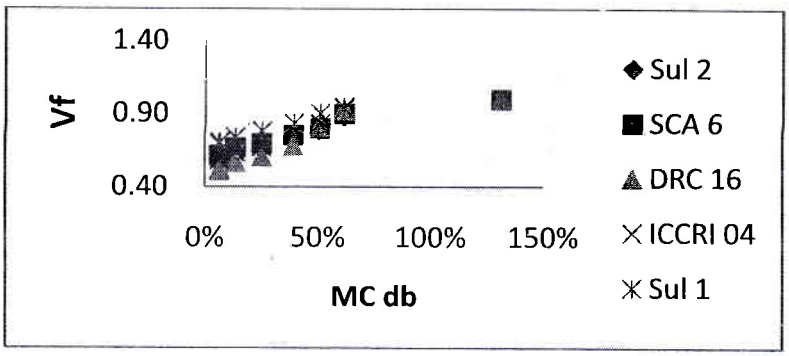

Figure 4. Cocoa bean volumetric shrinkage vs moisture content of five different cocoa clones

Table 2. The values of parameters involved in each volumetric shrinkage model being *evaluated.*

Equation Tag	b	A	C	R^2
Rahman Equation (1995)*)				
$V_f = 1 - b.(U-U_o)$				
Sulawesi 1	-0.258			0.821
DRC 16	-0.250			0.928
ICCRI 04	-0.274			0.893
SCA 6	-0.298			0.873
Sulawesi 2	-0.315			0.907
Adapted Bala & Wood's Equation (1984)*)				
$V_f = 1 - a.(1 - exp((b).(U-Uo)))$				
Sulawesi 1	0.003	82.107		0.821
DRC 16	0.001	276.757		0.928
ICCRI 04	0.001	271.741		0.893
SCA 6	0.001	229.364		0.872
Sulawesi 2	0.001	234.681		0.907

Table 2. The values of parameters involved in each volumetric shrinkage model being evaluated (continued)

[illegible]				
[illegible]				
Sulawesi 1	-0.179	1.510		0.682
DRC 16	-0.119	1.745		0.684
ICCRI 04	-0.171	1.663		0.707
SCA 6	-0.210	1.662		0.719
Sulawesi 2	-0.211	1.753		0.726
Proposed Model				
$V_f = a.U + b.U^2 + c$				
Sulawesi 1	-0.390	0.762	0.633	0.971
DRC 16	-0.095	0.467	0.468	0.980
ICCRI 04	-0.251	0.690	0.525	0.999
SCA 6	-0.348	0.778	0.568	0.994
Sulawesi 2	-0.224	0.660	0.523	0.980

Table 2 clearly indicated that the proposed model consistently provided higher R^2 for all clones compared to the other models. Corrêa et al. Equation (2004) which excellently represented the shrinkage behavior of coffee berry was found to be the most under-performed in this study. Rahman (1995), and Adapted Bala & Wood's Equation (1984), on the other hand, were good only to DRC 16 and Sulawesi-2 clones. The proposed model performances were shown in the following figure.

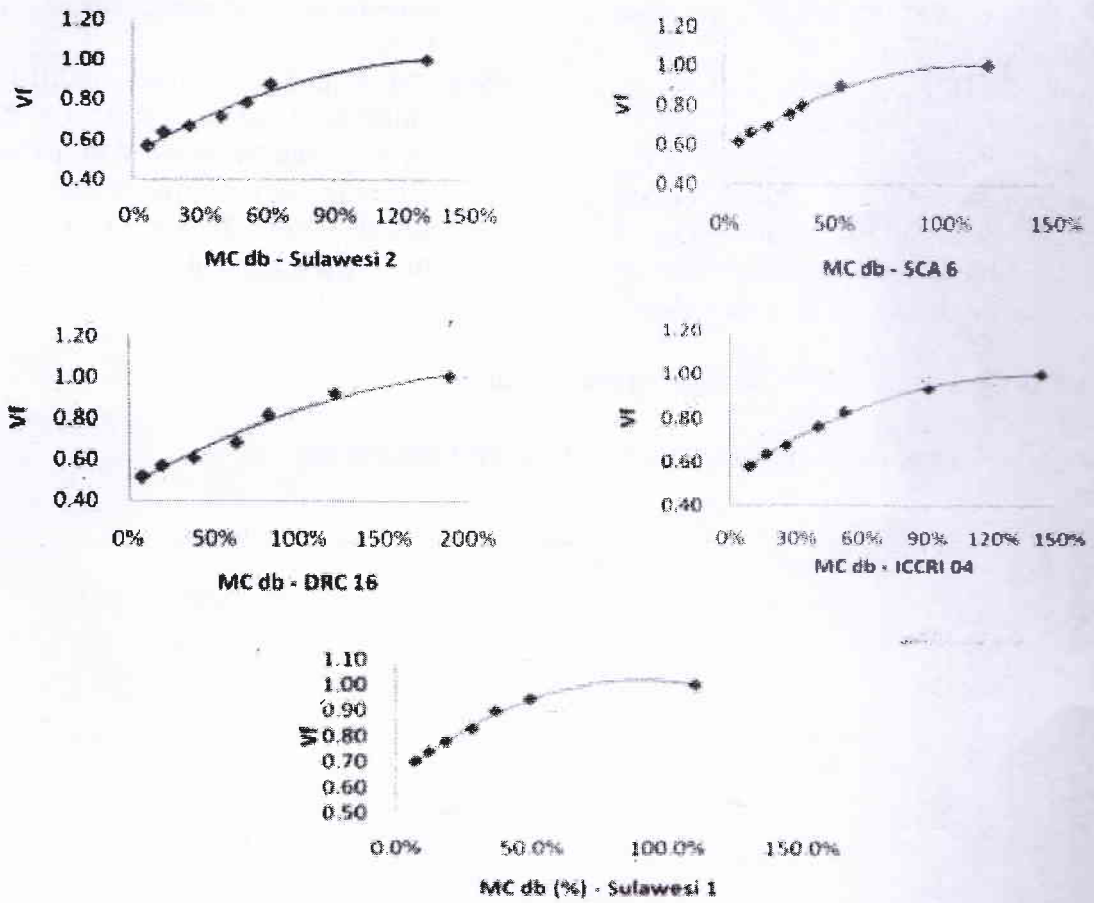

Figure 5. Performance of the proposed model (a polynomial model) in estimating the volumetric shrinkage behavior of five different cocoa clones.